Double Nickel Landslide Stabilization

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12th Int’l Workshop on Micropiles, Kraków, Poland
June 11-14, 2014
Acknowledgements

- Kirk Hood, PG
  - Project Geologist, WYDOT, Cheyenne, Wyoming
- Jamie Martens, PE and John Szturo, PG
  - Design Engineers, HNTB
- Norman Norrish, PE
  - Wyllie & Norrish Rock Engineers
- Jim Sexton, PE
  - Project Manager, Donald B. Murphy Contractors, Inc.
Outline

- Project Description
- Roadway/Landslide History
- General Geologic Setting
- Site and Subsurface Investigations
- Subsurface Characterization
- Engineering Analysis and Design
- Construction
- Post-Construction Monitoring
Project Description

- Stabilize a recurring landslide along Highway 28
  - Approximately 460 M in length
- Several previous re-alignments & repairs
- Accelerated design schedule
  - Kick-off Meeting July 14, 2011
  - Final Design submitted November 8, 2011
- Key Design Requirements
  - Maintain 2-way, 2-lane traffic during construction
  - Construction within the existing ROW
  - Static factor of safety = 1.3
Project Location
Roadway/Landslide History

- Pre-1985 Alignment
- 1985 “Straightened” Alignment
  - Landslide noted
  - Spring noted with underdrain installed
  - 12 m of roadway fill placed to bring roadway to grade
- Summer 1987 Initial Movement (fill settlement??)
- Further investigations continued thru 1992
- 1992 Toe Trench Drains
- 1994 Improvements
  - Roadway re-alignment upslope
  - Placement of lightweight fill
  - Four additional toe berms/drains and box culvert
- Continued Movement
Heavy snowfall w/rapid snowmelt in spring 2010 aggravated the landslide. More inclinometers along with piezos installed.
1994 Improvements
1994 Improvements
1994 Improvements
1994 Improvements
1994 Improvements
2012 Existing Conditions
General Geologic Setting

- Overburden over Tertiary-Aged White River Formation
- Erosional Unconformity with Pennsylvanian-Aged Formations
  - Tensleep Sandstone
  - Amsden Formation
  - Madison Limestone (Water Bearing)
- Existing Spring
Geologic Interpretation
Subsurface Investigations

- Previous WYDOT Investigations
  - Focused primarily on installing inclinometers or piezometers
  - Limited samples for testing
  - Drilling methods selected to achieve target depths

- HNTB developed a limited subsurface exploration program to support the design (late summer 2011)
  - Characterize the subsurface materials (soil and rock)
  - Install multi-level VWP’s to characterize pore water pressures
  - Identify potential shear planes
Boring Location Plan
Subsurface Characterization

- **Overburden**
  - Fill/Colluvium/Residuum
  - Highly Variable
  - Gravelly Clay to Clayey Gravel
  - Cobbles and Boulders
  - Fine Fraction Generally Plastic

- **Bedrock**
  - Highly variable
  - Shale, Siltstone, Claystone, Sandstone, Limestone, Quartzite, Chert
Subsurface Characterization
Subsurface Characterization
Subsurface Characterization

11-24 & 11-25
Summary of Data
Landslide Interpretation

Cross-Section at Slide Axis
Slope Stability Analysis

Double Nickel Landslide (Slide 6.0)

<table>
<thead>
<tr>
<th>Material Name</th>
<th>Color</th>
<th>Unit Weight (lb/cu ft)</th>
<th>Strength Type</th>
<th>Cohesion (lb/ft²)</th>
<th>Friction Angle (°)</th>
<th>Anisotropic Function</th>
<th>Water Surface</th>
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<td>Block Search Method</td>
<td>Water Surface</td>
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Landslide Stabilization Alternatives

- **Slope Grading**
  - Likely require additional ROW

- **Groundwater Control**
  - Drains would require additional ROW
  - Constructability issues (length, subsurface conditions)
  - Pump system would require on-going maintenance

- **Structural Reinforcement** *(Preferred Technique)*
Structural Reinforcement (Options)

- **Driven Piles**
  - High potential to encounter cobbles & boulders
  - High percentage of pre-drilling

- **Drilled Shafts**
  - Require fabrication of long reinforcing steel cages
  - High potential to encounter cobbles & boulders
  - Likely require temporary or permanent casing to install

- **Ground Anchors**
  - Require bearing blocks to distribute load
  - Constructability issues (long anchors, angled drilling, subsurface conditions)
  - Rigorous testing requirements
Shear Piles (Micropiles)

- Relatively small diameter
- Provide passive shear capacity
- Disrupt the slide plane
- Reinforce the soil mass
- Install vertically to reduce potential drilling difficulties
- Utilize dual rotary drilling technique for hole stability
- Minimal traffic impacts
Forward Slope Stability Analysis

Double Nickel Landslide

Bedrock Anisotropic Strength

Overburden w/ Relic Structure Anisotropic Strength

Material Name | Color | Unit Weight (lb/ft³) | Strength Type | Cohesion (lb/ft²) | phi | Anisotropic Function | Water Surface
--- | --- | --- | --- | --- | --- | --- | ---
Bedrock | 40 | Anisotropic Function | Bedrock | Piezometric Line 1
Pre-Sheared Zone | 130 | Mohr-Coulomb | 0 | 34 | Water Surface
Overburden (Relic Structure) | 123 | Anisotropic Function | Overburden w/ Relic Structure | Water Surface
Toe Bem | 127 | Mohr-Coulomb | 0 | 30 | Water Surface
Overburden | 123 | Mohr-Coulomb | 0 | 25 | Water Surface

Sta. 735+60
Forward Analysis - 4 Rows of Piles
Lateral Loading Parameters

- Resisting force required per pile = 2,000+ kN
- Per Reese and Van Impe (2011), force applied as a triangular pressure distribution above the slide surface (for piles weak in bending)
- Assumed soil present on the down slope side of pile
  - Pile considered a soil reinforcing element
  - Movement is episodic
  - Applied p-y reduction
Shear Pile Structural Evaluation

- Evaluated structural response of pile in shear, bending, and deflection with the triangular pressure distribution
- 225 kN·m bending moment
- Reduction for threaded joints
Final Design Recommendations

- 302 mm OD casing, 15 mm thick wall
- 4 Rows of Shear Piles
- Pile-to-Pile Spacing of 1.85 meters
- 6 meter (min) embedment below slide plane/bedrock contact
- Joint restrictions in the center of the slide
- Instrumentation to monitor shear pile response
Shear Pile Layout
Construction Contract Award

- Bid letting on January 12, 2012
- 7 ea. bids ranging from $17.6 to $21.2 million PLN
- Engineer’s estimate of $18.8 million PLN
- Contract awarded to Donald B. Murphy Contractors
- Construction began May 2012
Construction Planning

- **Drill Rig Selection**
  - Dual rotary to advance the bit with the casing
  - High torque and long stroke to accommodate the required joint restrictions
  - Two ABI 18/22 rigs selected

- **Permanent Casing**
  - Combined different lengths of casing to meet required tip elevations while minimizing waste
  - Matching casing length to inner drill rod lengths
  - Procurement of large casing quantity (14,650 meters)
Construction Planning

- Initial Drill Tooling Selection
  - Carbide-tipped “J” teeth welded to the lead end of the casing
  - Claw-type bit and 200 mm dth hammer with button bit

- Support Equipment
  - Primary flushing medium of air
  - Add water as necessary
  - Three 1,530 m³/hr/24 bar compressors
  - Handling equipment – crane & specially-equipped hydraulic excavators
Construction Progress

Mobilization & Site Preparation

- Grading and benching
- Grout plant and cement silos
- Settling pond

May 9, 2012
Shear Pile Installation

Demonstration Pile
Shear Pile Installation

Instrumentation Installation
Shear Pile Installation

Tooling and Bits
Shear Pile Installation
Shear Pile Installation
Shear Pile Installation

Subgrade Stabilization & Drainage Improvements
Shear Pile Installation

Before & After
Shear Pile Installation Summary

- Installation of 526 piles complete in 15 weeks
- 5 weeks of single rig, single shift production
- 10 weeks of two rig production
- Project completed within budget and on-schedule
Instrumentation & Monitoring

- Minimum 2-year post-construction monitoring period
- Inclinometers and strain meters
- Six (6) instrumented pile locations
- Overall system performance
Post-Construction Monitoring

- Baseline readings in October 2012
- Subsequent readings
  - May and October 2013
  - May 2014
- Maximum recorded strain less than 6% of theoretical
- Maximum recorded movement ~ 2.5 mm
Conclusions

- Designed landslide remediation met the aggressive schedule established by WyDOT
- Installed over 14,650 M of ~300 mm diameter micropiles in essentially 3 months
- Combination of inclinometers, strain meters, and piezometers allows monitoring of both geotechnical parameters and structural response
- Monitoring to-date indicates stable conditions with the shear piles performing satisfactorily